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Modeling contaminant plumes in fractured limestone aquifers

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Determining the fate and transport of contaminant plumes from contaminated sites in limestone aquifers is important because they are a major drinking water resource. This is challenging because they are often heavily fractured and contain chert layers and nodules, resulting in a complex transport behavior. Improved conceptual models are needed for this type of site. Here conceptual models are developed by combining numerical models with field data. Several types of fracture flow and transport models are available for the modeling of contaminant transport in fractured media. These include the established approaches of the equivalent porous medium, discrete fracture and dual continuum models. However, these modeling concepts are not well tested for contaminant plume migration in limestone geologies. Our goal was to develop and evaluate approaches for modeling the transport of dissolved contaminant plumes in fractured limestone aquifers in 3D and to test methods for determining the required flow and transport parameters.

The models were compared for a contaminated site in Denmark, where a plume of dissolved PCE has migrated through a fractured limestone aquifer. Numerical modeling was used in the planning of field tests and to update the conceptual model in an iterative process. Field data includes information on spill history, distribution of the contaminant (multilevel sampling), geology and hydrogeology. To describe the geology and fracture system, data from borehole logs, packer tests, optical televiewers and cores was combined with an analysis of local heterogeneities and data from analogous sites. A combined pump and tracer test was performed at the site with simultaneous contaminant sampling to determine flow and transport parameters of the fractures and matrix, and to quantify the contaminant distribution in the aquifer. Different models were used for the planning and interpretation of the pump and tracer test.

The models were evaluated by examining their ability to describe collected field data. The comparison with data showed that the models have substantially different representations of the contaminant behavior, with different consequences for evaluation of contaminant risk and potential remediation strategies. For instance, the fractured aquifer means that tracer tests result in fast breakthroughs, while larger scale plume transport is much slower. On the plume scale, the equivalent porous medium model and the dual-porosity model can reproduce the main features of the plume at a given time. However, small-scale fracture-matrix interactions such as diffusion of contaminant into the matrix result in non-linear plume speeds, and these cannot be represented with an equivalent-porous medium model. The paper concludes with recommendations on how to identify and employ suitable models to advance the conceptual understanding and as decision support tools for risk assessment and the planning of remedial actions.

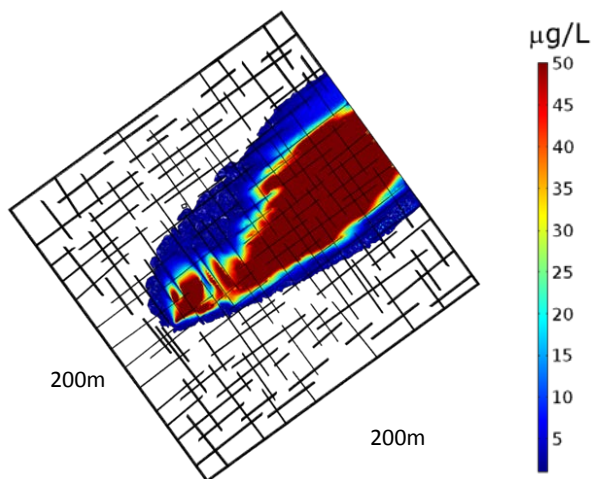


Figure 1: Dissolved PCE plume propagation in a fractured limestone using a 3D discrete-fracture model.